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(57) Abstract

Halocarbons such as CCl_2F_2, CF_3CFHCl or CF_3CFCl_2 which contain chlorine and/or bromine are contacted with hydrogen in the presence of silicon carbide and/or a metal selected from aluminum, molybdenum, titanium, nickel, iron or cobalt (or their alloys) at temperatures of 350° to 700 °C and pressures of 0 to 1000 psig to obtain a product wherein at least one chlorine or bromine in the starting material has been replaced by hydrogen.

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TITLE

HALOCARBON HYDROGENOLYSIS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. application Serial No. 07/418,832 filed October 10, 1989.

BACKGROUND OF THE INVENTION

This invention relates to a process for the hydrogenolysis of halocarbons.

At this time there is a desire to produce halocarbons of reduced chlorine content. Hydrogenolysis is a known method for doing this. For example, see U.K. Patent 1,578,933 which discloses a process for the hydrogenolysis of CF_3CFHCl to CF_3CH_2F using a hydrogenation catalyst, e.g., palladium supported on alumina or carbon. Hydrogenolysis of fluorochlorocarbons by passage through empty tubes made of various materials is also known, e.g., U.S. 2,615,926 discloses platinum tubes, U.S. 2,704,775 discloses nickel or stainless steel tubes and U.S. 3,042,727 discloses a Vycor® tube.

It is desired to provide a process for converting a halocarbon to a more hydrogenated form with high selectivity and particularly to provide such a process wherein formation of solids and plugging of reaction vessels is minimized.

SUMMARY OF THE INVENTION

We have discovered an improved hydrogenolysis process for reducing the chlorine and/or bromine content of halocarbons. The process may be used for producing saturated halocarbon products such that the yield loss to olefins, coupled by-products,

hydrocarbons or fragmented products is less than 10%. The process involves contacting a halocarbon of the formula:

$$C_nH_mF_pX_q$$

wherein X is Cl or Br,

n is 1 to 10,

m is 0 to 20,

p is 0 to 21,

q is 1 to 22, provided that m+p+q equals 2n+2 when the compound is acyclic and equals 2n when the compound is cyclic, and provided that when n is 1, q is at least 2, with at least 0.1 mole of hydrogen per mole of halocarbon at a temperature of 350° to 700°C, and a pressure of 0 to 1000 psig, in a reaction vessel (e.g., a tube) of aluminum, molybdenum, titanium, nickel, iron, cobalt, or their alloys, or of silicon carbide, optionally packed with aluminum, molybdenum, titanium, nickel, iron, cobalt or their alloys, or an inert material (e.g., silicon carbide) for a time sufficient to produce a product wherein at least one of X has been replaced by a hydrogen atom. Preferred alloys consist essentially of one or more metals selected from aluminum, molybdenum, titanium, nickel, iron and cobalt, optionally together with chromium and/or tungsten.

The process of the invention provides improved conversions and selectivity and has the further advantage that it does not produce olefins as the major product. Furthermore, the process minimizes the formation of solids in the reaction vessel, thus permitting long-term operation with less plugging.

DESCRIPTION OF THE INVENTION

An important aspect of the present invention is conducting the hydrogenolysis of halocarbons in the

presence of silicon carbide and/or at least one metal selected from aluminum, molybdenum, titanium, nickel, iron, cobalt or their alloys. The metals may be coated on the inside surface of a reaction vessel (e.g., by plating or sputtering the metals or their alloys onto the inside surface). Such coating can help to minimize corrosion of the reaction vessel well. A reaction vessel of these materials (e.g., a metal tube) optionally packed with the metal in suitable form or an inert material such as silica, silicon carbide or low surface area carbon (e.g., shot coke) may also be used. When reference is made to alloys, it is meant a nickel alloy containing from 1 to 99.9% (by weight) nickel, a cobalt alloy containing 1 to 99.9% (by weight) cobalt, an iron alloy containing 0.2 to 99.9% (by weight) iron, a molybdenum alloy containing 70 to 99.9% (by weight) molybdenum, an aluminum alloy containing 80 to 99.9% (by weight) aluminum and a titanium alloy containing 72 to 99.8% (by weight) titanium. Preferably the remainder of these alloys is selected such that the alloy consists essentially of (i) one or more metals selected from aluminum, molybdenum, titanium, nickel, iron and cobalt, and optionally (ii) chromium and/or tungsten.

Most preferred for the practice of this invention are nickel or alloys of nickel such as those containing 52% to 80% nickel, e.g., Inconel® 600 nickel alloy or Hastelloy® C276 alloy.

When used for packing, the metal, alloys or inert material may be particles or formed shapes such as, for example, perforated plates, saddles, rings (e.g., Pall® rings), wire, screen, chips, pipe, shot, gauze and wool. Although an empty reaction vessel

(e.g., an empty tube) may be used, the use of this type of packing material can provide the advantage of minimizing backmixing. These types of packing material can also serve as heat transfer materials. In many embodiments, perforated plates, saddles and rings can be especially useful.

The invention is applicable to the hydrogenolysis of halocarbons. The halocarbons can contain 1 to 10 carbon atoms, preferably 1 to 4 carbon atoms, most preferably 1 to 3 carbon atoms. The halocarbons include cyclic as well as acyclic compounds and can be generically represented by the empirical formula $C_nH_mF_pX_q$, where X is Cl and/or Br, preferably Cl, and n is an integer from 1 to 10, m is an integer from 0 to 20, p is an integer from 0 to 21, and q is an integer from 1 to 22, provided that m+p+q = 2n+2 when the compound is acyclic and equals 2n when the compound is cyclic. For single carbon compounds (i.e., n is 1) the invention is particularly applicable when q is at least 2.

In a preferred embodiment the halocarbons are represented by the above empirical formula where n = 1 to 4, m is 0 to 8, p is 0 to 9, and q is 1 to 9. Preferably, when n is 2 or more, p is at least 1.

The above halocarbons are either commercially available or can be prepared by known methods or adaptation of known methods.

As previously indicated these starting materials when subjected to the process of the invention will result in products wherein one or more X (e.g., chlorine) has been replaced by hydrogen. Thus the products of the hydrogenolysis reactions of the C_1 halocarbons will contain one or two hydrogen atoms, preferably one, and those from C_2 compounds

from one to three hydrogen atoms, preferably one to two. The C_3 halocarbons hydrogenolysis products will contain one to five hydrogen atoms with those containing one to four being preferred. In a similar manner the C_4 to C_{10} halocarbon products will contain one or more hydrogen atoms. The preferred process of this invention does not produce olefins as the major product. Instead, the major product of the conversion is a hydrogenolysis product wherein at least one X of the halocarbon starting material has been replaced by a hydrogen atom. This is particularly important for the hydrogenolysis of halocarbons where n is 2 to 10 (i.e., multicarbon halocarbons) where such factors as olefin production can be of concern at temperatures of 350°C or more. For example, CF_3CCl_2F can be converted with high selectivity to a hydrogenolysis product consisting primarily of CF_3CHClF and CF_3CH_2F with very little olefin formulation. In a preferred embodiment of this invention using halocarbons containing fluorine and chlorine, at least 90% of the hydrogenolysis products contain the same number of fluorines as the original halocarbon. Furthermore the yield loss to olefins, coupled by-products, hydrocarbons, fragmentation products or carbon is less than 10%.

Examples of olefins are products such as $CClF=CCF_2$ or $CF_2=CF_2$ the former of which can be obtained from hydrogenolysis of CCl_2FCClF_2 and the latter from hydrogenolysis of $CClF_2CClF_2$. An example of a coupled by-product is $CF_3CF=CFCF_3$ which can be obtained by the hydrogenolysis of $CClF_2CClF_2$. Examples of hydrocarbon products are CH_4, C_2H_6 and C_3H_8 which can be obtained by the hydrogenolysis of CCl_2F_2, CCl_2FCClF_2 and $CF_3CClFCF_3$ respectively.

Examples of fragmentation products are CF_3H and CH_2F_2 which can be obtained by the hydrogenolysis of CF_3CCl_2F and its isomer.

The reaction temperature can range from 350°C to 700°C. Preferably the reaction temperature is at least about 400°C.

The amount of hydrogen contained in the gas stream contacted with the gaseous halocarbon should be at least 0.1 mole per mole of halocarbon. Hydrogen amounts ranging from 0.2 to 5 moles per mole of halocarbon are used for some embodiments. In general, the amount of hydrogen preferably ranges from 0.2 to 60 moles per mole of halocarbon and more preferably ranges from 0.4 to 40 moles per mole of halocarbon. The hydrogen can be fed either in the pure state or diluted with an inert gas, e.g., nitrogen, helium, or argon.

The process pressure is operable over a broad range of pressures. Generally atmospheric (i.e., 0 psig) or superatmospheric pressures of up to 1000 psig are employed. Preferably the pressure is at least about 25 psig.

The extent of the replacement of halogen by hydrogen increases with reaction time. Reaction times between 0.1 minutes and 25 minutes are preferred. Most preferred are reaction times between 0.2 and 8 minutes.

An important feature of the process of the invention is that through selection of the appropriate metal and process conditions, a desired halocarbon hydrogenolysis product can be obtained as the major product with high selectivity and minimal formation of unwanted by-products. Preferably the reaction time and temperature are selected to obtain

long term (>1000 hours) plug free operation and to provide as the major product of the conversion hydrogenolysis product which retains the fluorine content of the starting halocarbon while at least one X is replaced by hydrogen. In many embodiments the reaction time and temperature are controlled so that at least about 90% of halocarbon converted has the same number of fluorine atoms as the halocarbon starting material. Also, in many embodiments the combined yield losses to olefins, coupled by-products, hydrocarbons, or fragmentation products is less than 10%.

An additional desirable feature is that through a selection of an appropriate reaction vessel and packing (e.g., metals, alloys, or inert materials) and process conditions, the products of the hydrogenolysis can contain in high selectivity just one less chlorine or bromine than was present in the starting material. This is particularly useful when q is 2 or more, and it is desired to obtain a major product of the conversion, hydrogenolysis product which contains chlorine and/or bromine. For example, starting with a one-carbon compound containing two or more chlorine or bromine atoms, products containing just one less chlorine or bromine can be obtained in high selectivity.

Although substantial conversions can be achieved in a once-through system, recycle of unreacted halocarbons or intermediates can be employed in a conventional manner. The processes of this invention are considered to be characterized by relativity high activation energies when compared to catalytic hydrogenolysis over conventional Pd/C catalyst. For example, the activation energy for the

hydrogenolysis of CF_3CCl_2F over a 0.5% Pd/C catalyst at 167°C to 200°C was found to be 14-17 Kcal/mole. The activation energy for the hydrogenolysis of CF_3CHClF over a 0.5% Pd/C catalyst at 249°C to 288°C was found to be 22-28 Kcal/mole. In contrast, the activation energies for the hydrogenolysis reactions of these compounds conducted in the reaction vessels of this invention, either empty or packed, were found to be considerably larger as exemplified in Table A.

TABLE A

Activation Energy Data

High Temperature Hydrogenolysis

Feed	Temp. Range	Packing	Activation Energy
$F114_a$[1]	450-550°C	-	49±3 Kcal/mole
$F114_x$[2]	440-600°C	-	47±2
F124[3]	510-600°C	-	49±7
$F114_x$	400-570°C	shot coke	35±1
$F114_x$	400-500°C	nickel screen	34±3
F124	510-570°C	Inconel® screen	41±3
F124	520-580°C	shot coke	37±1

[1] $F114_a$ = CF_3CCl_2F

[2] $F114_x$ = Du Pont commercial $CClF_2CClF_2$ containing some CF_3CCl_2F

[3] F124 = CF_3CHClF

The products of the reaction can be separated and purified by conventional means. The products can be used as solvents, blowing agents, refrigerants and propellants.

Practice of the invention will become further apparent from the following non-limiting examples. In the following Examples the following general procedure was employed, unless otherwise indicated.

General Procedure - A flow reactor under microprocessor control was used. The reactor, unless otherwise indicated, was a 15" x 1/4" o.d. or 3/8" o.d. Inconel® 600 nickel alloy tube or a 15" x 3/8" Hastelloy® C276 nickel alloy tube bent into a U shape and immersed in a heated fluidized sand bath for temperature control. Inconel® 600 is a commercial alloy containing 76% nickel, 15.5% chromium and 8% iron. Hastelloy® C-276 is a commercial alloy containing 59% nickel, 15.5% chromium, 16% molybdenum and 3.75% tungsten.

The reactor was used either empty or filled with various packing materials as described in the Examples. Hydrogen gas was metered into the system through mass flow controllers. Liquid halocarbons were fed from a syringe pump and vaporized before entering the reactor. Conversions and yields were measured by taking gas stream samples into a gas chromatograph. Product identification was by gc retention times with confirmation by gc-mass spectrometer analysis of samples.

EXAMPLE 1

$$CF_3CCl_2F + H_2 \longrightarrow CF_3CHClF + CF_3CH_2F$$

2,2-Dichloro-1,1,1,2-tetrafluoroethane (1.47 g/hr) and hydrogen (molar ratio of H_2/CF_3CCl_2F = 1.9) were fed into the 1/4" empty Inconel® nickel alloy reactor for 38 hours at 450°-550°C and 250 psig. A sample taken after 14 hours at 550°C showed an 89% conversion of CF_3CCl_2F with a 65% selectivity to CF_3CHClF and a 32% selectivity to CF_3CH_2F. Overall selectivity to the two products was 97%.

EXAMPLE 2

$$CF_3CCl_2F + H_2 \text{ ----> } CF_3CHClF + CF_3CH_2F$$

2,2-Dichloro-1,1,1,2-tetrafluoroethane (1.47 g/hr) and hydrogen (molar ratio of H_2/CF_3CCl_2F = 1.9) were fed into the 1/4" empty Inconel® nickel alloy reactor for 132 hours at 350°-550°C and 250 psig. At 350°C a 2.3% conversion of CF_3CCl_2F with a 76% selectivity to CF_3CHClF and CF_3CH_2F was observed. A sample taken after 20 hours at 500°C showed an 83% conversion of CF_3CCl_2F with a 98% selectivity to CF_3CHClF and CF_3CH_2F.

EXAMPLE 3

$$CF_3CHClF + H_2 \text{ ----> } CF_3CH_2F$$

2-Chloro-1,1,1,2-tetrafluoroethane (1.0 g/hr) and hydrogen (molar ratio of H_2/CF_3CCl_2F = 4.9) were fed into the 1/4" empty Inconel® nickel alloy reactor for 7 hours at 550°C and 250 psig with average CF_3CHClF conversions of 86% with 98% selectivity to CF_3CH_2F and 0.4% selectivity to CF_3CH_3.

EXAMPLE 4

$$CF_2Cl_2 + H_2 \text{ ----> } CF_2HCl$$

Dichlorodifluoromethane (9.0 g/hr) and hydrogen (molar ratio of H_2/CF_2Cl_2 = 1.0) were fed into the 1/4" empty Inconel® nickel alloy reactor as described above for 89 hours at 300 psig, including 79 hours at 500-550°C. For 12 hours at 500°C during this run, at a mean age of 64 synthesis hours, the average conversion of CF_2Cl_2 was 26% with a 97% selectivity to CF_2HCl and a 3% selectivity to CH_2F_2.

EXAMPLE 5

$$CF_3CClFCF_3 + H_2 \text{ ----> } CF_3CHFCF_3$$

2-Chloroheptafluoropropane (1.5 g/hr) and hydrogen (22 cc/min) were fed into the 1/4" empty

Inconel® nickel alloy reactor for 3 hours at 450°C and 250 psig with 30-40% conversion and a 98% selectivity to CF_3CHFCF_3.

EXAMPLE 6

$$CF_3CClFCF_3 + H_2 \text{ ----> } CF_3CHFCF_3$$

2-Chloroheptafluoropropane (1.38 g/hr) and hydrogen (22 cc/min) were fed into the 1/4" Inconel® nickel alloy reactor filled with Inconel® nickel alloy chips (10 g). Operation at 500°C and 250 psig for 33.3 hours gave an average of 91.3% conversion with 99.4% selectivity to CF_3CHFCF_3.

EXAMPLE 7

$$CF_3CCl_2F + H_2 \text{ ----> } CF_3CHClF + CF_3CH_2F$$

2,2-Dichloro-1,1,1,2-tetrafluoroethane (2.9 or 5.9 g/hr) and hydrogen (molar ratio of H_2/CF_3CCl_2F = 2.2 or 4.3) were fed into the 3/8" Inconel® nickel alloy reactor filled with Inconel® nickel alloy wool (7.96 g) for 106 hours at 400-500°C and 250 psig. The average conversion of CF_3CCl_2F over the whole period was 99.9%. For a 12-hour period at 450°C with a CF_3CCl_2F feed rate of 5.9 g/hr (molar ratio H_2/CF_3CCl_2F = 4.3) the following average selectivities were observed: 69% CF_3CHClF and 26% CF_3CH_2F.

EXAMPLE 8

$$CF_3CHClF + H_2 \text{ ----> } CF_3CH_2F$$

2-Chloro-1,1,1,2-tetrafluoroethane (5.5 g/hr) and hydrogen (molar ratio of H_2/CF_3CHClF = 1.1) were fed into the 3/8" Inconel® nickel alloy reactor filled with a pure nickel screen (8.77 g), operated at various feed rates and a pressure of 300 psig. With a CF_3CHClF feed rate of 5.48 g/hr and hydrogen (molar ratio of H_2/CF_3CHClF = 1.1) conversion at 525°C and an average synthesis time of 82 hours

averaged 47% with 98% selectivity to CF_3CH_2F for 12 hours. At an average synthesis time of 644 hours conversion averaged 39% with 97% selectivity to CF_3CH_2F. At 1181 synthesis hours the operating pressure was increased to 500 psig. Conversion of CF_3CHClF averaged 68% for 14 hours with a selectivity to CF_3CH_2F of 98%.

EXAMPLE 9

$$CF_3CHClF + H_2 \text{ ----> } CF_3CH_2F$$

2-Chloro-1,1,1,2-tetrafluoroethane (2.7 or 5.5 g/hr) and hydrogen (molar ratio of H_2/CF_3CHClF = 1.9) were fed into the 3/8" Inconel® nickel alloy reactor filled with Inconel® nickel alloy wool (7.96 g) for 23 hours at 400-500°C and 250 psig. Between 18 and 23 hours, at 400°C with a CF_3CHClF feed rate of 2.7 g/hr, the average conversion was 23% and the selectivity to CF_3CH_2F was 82%.

EXAMPLE 10

$$CF_2Cl_2 + H_2 \text{ ----> } CF_2HCl$$

Dichlorodifluoromethane (4.5 or 33.0 g/hr) and hydrogen (molar ratio of H_2/CF_2Cl_2 = 1 or 0.5) were fed into the 3/8" Inconel® nickel alloy reactor filled with pure nickel screen (17.5 g) for 135 hours at 300 psig. For 12 hours at 450° during this run, at a mean synthesis time of 78 hours, with a CF_2Cl_2 feed rate of 4.5 g/hr (molar ratio H_2/CF_2Cl_2 = 1.0), the average conversion of CF_2Cl_2 was 34% with the following average selectivities: 95% CF_2HCl and 2.9% CF_2H_2.

EXAMPLE 11

$$CF_3CClF_2 + H_2 \text{ ----> } CF_3CHF_2$$

Chloropentafluoroethane vapor (6 cc/min) and hydrogen (5 cc/min) were fed into a Hastelloy® nickel alloy reactor (6" x 1/2" O.D.) filled with pure

nickel screen (39.68 g) at 550°C and atmospheric pressure. The reaction products were analyzed with the following results: 59% conversion of CF_3CClF_2 with a 97% selectivity to CF_3CHF_2.

EXAMPLE 12

$$CF_3CClF_2 + H_2 \text{ ----> } CF_3CHF_2$$

Chloropentafluoroethane vapor (5 cc/min) and hydrogen (6 cc/min) were fed into an Inconel® nickel alloy reactor (6" x 1/2" O.D.) filled with pure nickel screen (51.98 g) at 550°C and atmospheric pressure. The reaction products were analyzed with the following results: 65% conversion of CF_3CClF_2 with a 95% selectivity to CF_3CHF_2.

The reaction was run under the same conditions as described above, except that the feed rates were changed to CF_3CClF_2 (5 cc/min) and H_2 (12 cc/min). The reaction products were analyzed with the following results: 62% conversion of CF_3CClF_2 with an 86% selectivity to CF_3CHF_2.

EXAMPLE 13

$$CClF_2CClF_2/CF_3CCl_2F + H_2 \text{ ----}$$
$$CHF_2CClF_2/CF_3CHClF + CHF_2CHF_2/CF_3CH_2F$$

A vapor mixture of $CClF_2CClF_2(9)/CF_3CCl_2F(1)$ (5 cc/min) and hydrogen (6 cc/min) was fed into a Hastelloy® nickel alloy reactor (6" x 1/2" O.D.) filled with pure nickel screen (39.68 g) at 550°C and atmospheric pressure. The reaction products were analyzed with the following results: 61% conversion of $CClF_2CClF_2/CF_3CCl_2F$ with a 46% selectivity to CHF_2CClF_2/CF_3CHClF and a 34% selectivity to CHF_2CHF_2/CF_3CH_2F.

EXAMPLE 14

$CF_3CCl_2F + H_2$ ----> $CF_3CHClF + CF_3CH_2F$

2,2-Dichlorotetrafluoroethane vapor (5 cc/min) and hydrogen (6 cc/min) were fed into an Inconel® nickel alloy reactor (6" x 1/2" O.D.) filled with pure nickel screen (51.98 g) at 550°C and atmospheric pressure. The reaction products were analyzed with the following results: 83% conversion of CF_3CCl_2F with a 5% selectivity to CF_3CHClF and a 66% selectivity to CF_3CH_2F.

EXAMPLE 15

$CF_3CHClF + H_2$ ----> CF_3CH_2F

2-Chloro-1,1,1,2-tetrafluoroethane vapor (5 cc/min) and hydrogen (6 cc/min) were fed into an Inconel® nickel alloy reactor (6" x 1/2" O.D.) filled with pure nickel screen (51.98 g) at 550°C and atmospheric pressure. The reaction products were analyzed with the following results: 58% conversion of CF_3CHClF with an 85% selectivity to CF_3CH_2F.

EXAMPLE 16

$CClF_2CCl_2F + H_2$ ----> $CHClFCClF_2 + CHClFCHF_2$

1,1,2-Trichloro-1,2,2-trifluoroethane (3.13 g/hr) and hydrogen (molar ratio = 4.75) were fed into the 3/8" Inconel® nickel alloy U-tube reactor as described in the general procedure, with the exit leg filled with pure nickel screen (8 g), at 450°C and 500 psig. Over a 6-hour period the reaction products were analyzed with the following results: 81% conversion of CCl_2FCClF_2 with 96% combined selectivity to $C_2H_3F_3$, $C_2H_2ClF_3$, and $C_2HCl_2F_3$. Selectivity to $CClF = CF_2$ was 2%. When the temperature was raised to 475°C for 7 hours, the average conversion of CCl_2FCClF_2 was 97% with 95% combined selectivity to $C_2H_3F_3$, $C_2H_2ClF_3$, and $C_2HCl_2F_3$. Selectivity to $CClF = CF_2$ was 1%.

EXAMPLE 17

$CF_3CHClF + H_2 \dashrightarrow CF_3CH_2F$

2-Chloro-1,1,1,2-tetrafluoroethane (2.7 g/hr) and hydrogen (molar ratio of $H_2/CF_3CHClF = 0.2$) were fed into an empty 6" x 1/2" O.D. Hastelloy® C276 nickel alloy reactor for 8 hours at 535°C and 300 psig. The average conversion of CF_3CHClF was 22% with an average 97% CF_3CH_2F selectivity.

EXAMPLE 18

$CF_3CHClF + H_2 \dashrightarrow CF_3CH_2F$

2-Chloro-1,1,1,2-tetrafluoroethane (2.7 g/hr) and hydrogen (molar ratio of $H_2/CF_3CHClF = 1.5$) were fed into 6" x 1/2" O.D. Hastelloy® C276 nickel alloy reactor containing 14/20 mesh acid-washed SiC (6.5 g) for 60 hours at 535°C and 300 psig. The average conversion of CF_3CHClF was 75% with an average 97% CF_3CH_2F selectivity.

EXAMPLE 19

$CF_3CHClF + H_2 \dashrightarrow CF_3CH_2F$

2-Chloro-1,1,1,2-tetrafluoroethane and hydrogen were fed at various rates over 113 hours into the 3/8" Hastelloy® C276 nickel alloy tube operated at 300 psig and containing Conoco Shot coke (9.2 grams, 10 cc), a highly fused petroleum coke with a surface area of 0.5 sq m/g. For an 8-hour period at 560°C and an average time in synthesis of 102 hours, with a CF_3CHClF feed rate of 11.0 g/hr and a hydrogen feed rate of 32 cc/min (molar ratio of $H_2/CF_3CHClF = 1$) the average conversion of CF_3CHClF was 13% with an average selectivity to CF_3CH_2F of 99%.

EXAMPLE 20

$CClF_2CClF_2 + H_2 \dashrightarrow CHF_2CClF_2 + CHF_2CHF_2$

Commercial 1,2-dichloro-1,1,2,2-tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2-

tetrafluoroethane, and hydrogen were fed at various rates over 150 hours into the 3/8" Inconel® nickel alloy tube operated at 300 psig and containing Conoco Shot coke (9.2 grams, 10 cc), a highly fused petroleum coke with a surface area of 0.5 sq. m/g. For a 16-hour period at 550°C and an average time in synthesis of 59 hours, with a $CClF_2CClF_2$ feed rate of 5.9 g/hr and a hydrogen feed rate of 28 cc/min (molar ratio of $H_2/CClF_2CClF_2$ = 2) the average conversion of the $C_2Cl_2F_4$ isomers was 84% with an average selectivity to CHF_2CClF_2 and its isomer of 49%, and an average selectivity to CHF_2CHF_2 and its isomer of 47%.

EXAMPLE 21

$CF_3CCl_2F + H_2$ ----> $CF_3CHClF + CF_3CH_2F$

2,2-Dichloro-1,1,1,2-tetrafluoroethane (2 mL/h), which was vaporized before being mixed with hydrogen (13 cc/min), was fed into a Hastelloy® C nickel alloy reactor (6" x 1/2" O.D.) as described above, containing Conoco Shot coke (14.0 grams, 10 mesh), a highly fused petroleum coke with a surface area of 0.5 sq m/g at 550°C and 100 psig. After 28 hours of operation, product analysis indicated that CF_3CCl_2F conversion was quantitative and selectivity to CF_3CHClF and CF_3CH_2F was 64.7% and 33.3% respectively.

EXAMPLE 22

$CF_3CClF_2 + H_2$ ----> CF_3CHF_2

Chloropentafluoroethane vapor (10 cc/min) and hydrogen (10 cc/min) were fed into a Hastelloy® C nickel alloy reactor (6" x 1/2" O.D.) as described above, charged with Conoco Shot coke (14.0 grams, 10 mesh), a highly fused petroleum coke with a surface area of 0.5 sq m/g at 550°C. After 10 hours of

operation, product analysis indicated that CF_3CClF_2 conversion was 7.5% and selectivity to CF_3CHF_2 was 94.7%.

This experiment was substantially repeated except that the CF_3CClF_2 flow was 5 cc/min and the hydrogen flow was 6 cc/min. Product analysis indicated that CF_3CClF_2 conversion was 13.3% and selectivity to CF_3CHF_2 was 89.6%.

EXAMPLE 23

$$CClF_2CClF_2 + H_2 \dashrightarrow CHF_2CClF_2 + CHF_2CHF_2$$

Commercial 1,2-dichloro-1,1,2,2-tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2-tetrafluoroethane, and hydrogen were fed at various rates for 172 hours into an empty 15" x 3/8" O.D. Hastelloy® C276 nickel alloy tube, as described above, operated at 500 psig. For a 13 hour period at 500°C and an average time in synthesis of 66 hours, with a $CClF_2CClF_2$ feed rate of 5.9 g/hr and hydrogen feed rate of 10 cc/min (molar ratio of $H_2/CClF_2CClF_2 = 0.7$) the average conversion of $C_2Cl_2F_4$ isomers was 58% with an average selectivity to CHF_2CClF_2 and its isomer of 75% and an average selectivity to CHF_2CHF_2 and its isomer of 24%. For a 9 hour period at 500°C and an average time in synthesis of 148 hours, with a $CClF_2CClF_2$ feed rate of 1.47 g/hr and a molar feed ratio of $H_2/CClF_2CClF_2$ of 1.5 the average conversion of $C_2Cl_2F_4$ isomers was 88% with an average selectivity of CHF_2CClF_2 and its isomer of 45% and an average selectivity to CHF_2CHF_2 and its isomer of 54%.

EXAMPLE 24

$CClF_2CClF_2 + H_2 \dashrightarrow CHF_2CClF_2 + CHF_2CHF_2$

Commercial 1,2-dichloro-1,1,2,2-tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2-tetrafluoroethane, and hydrogen were fed at various rates for 192 hours into a 15" x 3/8" O.D. Inconel® 600 nickel alloy tube, as described above, containing 8.0 g of 24 x 100 mesh nickel screen and operated at 500 psig. For a 10 hour period at 400°C and a $CClF_2CClF_2$ feed rate of 0.7 g/hr and hydrogen feed rate of 1.7 cc/min (molar ratio of $H_2/CClF_2CClF_2$ = 1); the average conversion of $C_2Cl_2F_4$ isomers was 61% with an average selectivity to CHF_2CClF_2 and its isomer of 77.0% and an average selectivity to CHF_2CHF_2 and its isomer of 22.7%.

EXAMPLE 25

$CF_3CCl_2F + H_2 \dashrightarrow CF_3CHClF + CF_3CH_2F$

2,2-Dichloro-1,1,1,2-tetrafluoroethane and hydrogen were fed at various rates for 68 hours to an empty Hastelloy® C276 nickel alloy tube, as described above, operated at 500 psig. For a five hour period at 500°C and an average time in synthesis of 41 hours, with a CF_3CCl_2F feed rate of 5.9 g/hr and a hydrogen rate of 14 cc/min (molar ratio of H_2/CF_3CCl_2F = 1), the average conversion was 64% with an average selectivity to CF_3CHClF of 83.6 and an average selectivity of CF_3CH_2F of 15.6%.

EXAMPLE 26

$CClF_2CClF_2 + H_2 \dashrightarrow CHF_2CClF_2 + CHF_2CHF_2$

Chrome-Plated Reactor

Commercial 1,2-dichloro-1,1,2,2 tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2

tetrafluoroethane, and hydrogen were fed at various rates over 55 hours into a 15" x 1/4" o.d. empty chrome-plated U-tube reactor, as described above, operated at 300 psig. For a 20-hour period at 500°C and an average time in synthesis of 16 hours, with a $CClF_2CClF_2$ feed rate of 2.9 g/hr and a hydrogen feed rate of 13.3 cc/min (molar ratio $H_2/CClF_2CClF_2 = 2$); the average conversion of the $CClF_2CClF_2$ isomers was 56% with an average selectivity to CHF_2CClF_2 and its isomer of 21%, and an average selectivity to CHF_2CHF_2 and its isomer of 76%.

EXAMPLE 27

$$CClF_2CClF_2 + H_2 \text{ ---> } CHF_2CClF_2 + CHF_2CHF_2$$

Aluminum Reactor

Commercial 1,2-dichloro-1,1,2,2 tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2 tetrafluoroethane, and hydrogen were fed at various rates over 31 hours into an empty 15" x 1/4" o.d. aluminum U-tube reactor, as described above, operated at 50 psig. For a 3-hour period at 500°C and an average time in synthesis of 28 hours, with a $CClF_2CClF_2$ feed rate of 1.47 g/hr and a hydrogen feed rate of 7.0 cc/min (molar ratio $H_2/CClF_2CClF_2 = 2$); the average conversion of the $CClF_2CClF_2$ isomers was 5% with an average selectivity to CHF_2CClF_2 and its isomer of 49%, and an average selectivity to CHF_2CHF_2 and its isomers of 33%.

EXAMPLE 28

$$CClF_2CClF_2 + H_2 \text{ ---> } CHF_2CClF_2 + CHF_2CHF_2$$

Titanium Reactor

Commercial 1,2-dichloro-1,1,2,2 tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2-

tetrafluoroethane, and hydrogen were fed at various rates over 42 hours into a 15" x 1/4" o.d. empty titanium U-tube reactor, as described above, operated at 50 psig. For a 17-hour period at 500°C and an average time in synthesis of 9.5 hours, with a $CClF_2CClF_2$ feed rate of 2.9 g/hr and a hydrogen feed rate of 13.9 cc/min (molar ratio $H_2/CClF_2CClF_2$ = 2) the average conversion of the $CClF_2CClF_2$ isomers was 14.2% with an average selectivity to CHF_2CClF_2 and its isomer of 57%, and an average selectivity to CHF_2CHF_2 and its isomer of 24.4%.

EXAMPLE 29

$CF_3CHClF + H_2$ ---> CF_3CH_2F

Silicon Carbide Reactor

2-Chloro-1,1,1,2 tetrafluoroethane and hydrogen were fed at various rates over 47 hours into a 15" x 1/4" o.d. empty silicon carbide straight tube reactor, as described above, operated at 0 psig. For a 12-hour period at 600°C and an average time in synthesis of 29 hours, with a CF_3CHClF feed rate of 2.74 g/hr and a hydrogen feed rate of 8.2 cc/min (molar ratio H_2/CF_3CHClF = 1); the average conversion of the CF_3CHClF was 4.3%, with an average selectivity to CF_3CH_2F of 89.7%.

EXAMPLE 30

$CF_3CCl_2F + H_2$ ---> $CF_3CHClF + CF_3CH_2F$

Silicon Carbide Reactor

2,2-Dichloro-1,1,1,2-tetrafluoroethane 2.94 g/hr were fed into a silicon carbide straight tube reactor, as described above, with 6.4 cc/min of hydrogen (molar ratio H_2/CF_3CCl_2F = 1) operated at 0 psig for 41 hours. Over a 15-hour period at 500°C

and an average time in synthesis of 27 hours; the average conversion of CF_3CCl_2F was 23% with an average selectivity to CF_3CHClF of 54% and an average selectivity to CF_3CH_2F of 0.6%.

EXAMPLE 31

$CClF_2CClF_2 + H_2 \text{ ---> } CHF_2CClF_2 + CHF_2CHF_2$

Silicon Carbide Reactor

Commercial 1,2-dichloro-1,1,2,2 tetrafluoroethane, containing 9% (molar) 1,1-dichloro-1,2,2,2 tetrafluoroethane, and hydrogen were fed at various feed rates over 38 hours into a straight tube silicon carbide reactor tube, as described above, operated at 0 psig. For a 12-hour period at 575°C and at an average time in synthesis of 14 hours, with a feed rate of 13.9 cc/min of hydrogen and 2 grams/hr of $CClF_2CClF_2$ (molar ratio $H_2/CClF_2CClF_2 = 2$); the average conversion of the $CClF_2CClF_2$ isomers was 35.6% with an average selectivity to CHF_2CClF_2 and its isomers of 28% and an average selectivity to CHF_2CHF_2 and its isomers of 27%.

EXAMPLE 32

$CF_2Cl_2 + H_2 \text{ ---> } CF_2HCl + CH_2F_2$

Silicon Carbide Reactor

Dichlorodifluoromethane (2.6 g/hr) and hydrogen (molar ratio $H_2/CF_2Cl_2 = 1.0$) were fed into an empty 1/2" x 15" silicon carbide straight tube reactor, as described above, over a 28-hour period. For four hours at 575°C during this run, at an average synthesis time of 26 hours; the average conversion of CF_2Cl_2 was 35.6% with an 82% selectivity to CF_2HCl and a 2% selectivity to CH_2F_2.

EXAMPLE 33

$CF_3CCl_3 + H_2 \text{---}> CF_3CHCl_2 + CF_3CH_2Cl$

Hastelloy® Nickel Alloy Reactor

1,1,1-Trichloro-2,2,2-trifluoroethane and hydrogen were fed into an empty 15" x 3/8" Hastelloy® C276 nickel alloy U-tube reactor, as described above, at 300 psig for a period of 28 hours. Over a 6-hour period at 425°C and 300 psig, at an average time in synthesis of 17 hours, with a feed rate of CF_3CCl_3 of 6.25 g/hr and a hydrogen feed rate of 14.0 sccm (molar ratio H_2/CF_3CCl_3 = 1.0); the average conversion of CF_3CCl_3 was 33% with a selectivity to CF_3CHCl_2 of 95% and a selectivity to CF_3CH_2Cl of 5%.

EXAMPLE 34

$CCl_4 + H_2 \text{---}> CHCl_3 + CH_2Cl_2$

Inconel® Nickel Alloy Reactor

Carbon tetrachloride (6.57 g/hr) and hydrogen (200 sccm) were fed into an empty 15" x 1/4" Inconel® 600 nickel alloy U-tube reactor, as described above, operated at pressures between 0 psig and 300 psig for 149 hours. For a 10-hour period at 457°C and 300 psig and an average time in synthesis of 136 hours, with a CCl_4 feed rate of 6.57 g/hr and a hydrogen feed rate of 200 sccm (molar ratio H_2/CCl_4 = 12); the average conversion of CCl_4 was 45% with an average selectivity to $CHCl_3$ of 59% and an average selectivity to CH_2Cl_2 of 2.8%.

EXAMPLE 35

$CF_3CHClF + H_2 \text{---}> CF_3CH_2F$

High Hydrogen Ratio

2-Chloro-1,1,1,2-tetrafluoroethane and hydrogen were fed at varying rates for over 48 hours to a 56"

x 1/4" Inconel® 600 nickel alloy coil reactor at 300 psig and temperatures between 550 and 600°C. For 4 hours at 600°C, at an average time in synthesis of 39 hours, with a CF_3CHClF feed rate of 1.6 mL/hr and a H_2 feed rate of 130 sccm (H_2/CF_3CHClF mol ratio = 20) the average conversion of CF_3CHClF was 83% and the selectivity to CF_3CH_2F was 94%. At a lower H_2 flow of 65 sccm and the same CF_3CHClF feed rate and temperature (H_2/CF_3CHClF mol ratio = 10) the average conversion of CF_3CHClF over a 5-hour period was 90% with a 94% selectivity to CF_3CH_2F.

EXAMPLE 36

$$CF_3CHClF + H_2 \dashrightarrow CF_3CH_2F$$

High Hydrogen Ratio

2-Chloro-1,1,1,2-tetrafluoroethane and hydrogen were fed at various rates for 1207 hours into a 15" x 3/8" Inconel® 600 nickel alloy U-tube, packed with 8.77 g 150 mesh nickel screen, and operated at various temperatures at 300 psig. For a 23-hour period at 550°C and an average time in synthesis of 755 hours with a CF_3CHClF feed rate of 0.4 ml/hour and a hydrogen feed rate of 18 sccm/min (molar ratio H_2/CF_3CHClF = 11), the average conversion of CF_3CHCl was 99.6% with a selectivity to CF_3CH_2F of 93%.

EXAMPLE 37

$$CCl_2FCF_3 + H_2 \dashrightarrow CHClFCF_3 + CH_2FCF_3$$

High Hydrogen Ratio

1,1-Dichloro-1,2,2,2-tetrafluoroethane and hydrogen were fed at various rates for 237 hours into a 15" x 3/8" Hastelloy® C nickel alloy U-tube packed with 9.29 g of Conoco shot coke and operated at various temperatures at 300 psig. For a 5-hour

period at 575°C and an average time in synthesis of 227 hours with a CCl_2FCF_3 feed rate of 36 mL/hr and a hydrogen feed rate of 50 sccm/min (molar ratio $H_2/CCl_2FCF_3 = 40$), the average conversion of CCl_2FCF_3 was 100%. The selectivity to $CHClFCF_3$ was 32% and the selectivity to CH_2FCF_3 was 59%.

EXAMPLE 38

$$CF_3CClF_2 + H_2 \text{ ---> } CF_3CHF_2$$

2-Chloro-1,1,1,2,2-pentafluoroethane and hydrogen were fed at various rates to 15" x 3/8" Hastelloy® C276 nickel alloy U-tube operated at 300 psig and various temperatures for 136 hours. For 10 hours, at an average time in synthesis of 58 hours and a temperature of 575°C, with a CF_3CClF_2 feed rate of 2.1 g/hr and a hydrogen feed rate of 14.0 sccm (molar ratio $H_2/CF_3CClF_2 = 2.5$), the conversion of CF_3CClF_2 was 89.5% and the selectivity to CF_3CHF_2 was 99.9%.

For an 8-hour period at an average time in synthesis of 131 hours and a temperature of 575°C, with a feed rate of CF_3CClF_2 of 4.15 g/hr and a hydrogen feed rate of 329 sccm (molar ratio $H_2/CF_3CClF_2 = 30$), the average conversion of CF_3CClF_2 was 39% with a selectivity to CF_3CHF_2 was 99.6%.

Particular embodiments of the invention are included in the examples. Other embodiments will become apparent to those skilled in the art from a consideration of the specification or practice of the invention disclosed herein. It is understood that modifications and variations may be practiced without departing from the spirit and scope of the novel concepts of this invention. It is further understood

that the invention is not confined to the particular formulations and examples herein illustrated, but it embraces such modified forms thereof as come within the scope of the following claims.

CLAIMS

1. A process for the hydrogenolysis of halocarbons comprising: contacting a halocarbon of the formula

$$C_nH_mF_pX_q$$

wherein X is Cl or Br,

n is 1 to 10,

m is 0 to 20,

p is 0 to 21,

q is 1 to 22, provided that m+p+q equals 2n+2 when the compound is acyclic and equals 2n when the compound is cyclic, and provided that when n is 1, q is at least 2, with at least 0.1 mole of hydrogen per mole of said halocarbon in a reaction vessel of aluminum, molybdenum, titanium, nickel, iron, cobalt, or their alloys or of silicon carbide, which is either empty or is packed with particles or formed shapes of aluminum, molybdenum, titanium, nickel, iron, cobalt, or their alloys or silicon carbide or low surface area carbon at a pressure within the range of from 0 psig to 1000 psig, at a temperature within the range of from 350°C to 700°C and for a time sufficient to produce a product wherein at least one of X has been replaced by a hydrogen atom.

2. The process of Claim 1 wherein the temperature ranges from 400°C to 700°C and the pressure is 0 to 500 psig.

3. The process of Claim 1 wherein X is Cl, n is 1 to 4, m is 0 to 8, p is 0 to 9 and q is 1 to 9.

4. The process of Claim 3 wherein n is 1 to 3.

5. The process of Claim 1 wherein the halocarbon is selected from CF_3CCl_2F, CF_3CHClF, CCl_4, CCl_2F_2, $CClF_2CClF_2$, CHF_2CClF_2, C_2F_5Cl, $CClF_2CCl_2F$, CF_3CCl_3, CCl_2FCCl_2F or $CClF_2CCl_3$.

6. The process of Claim 1 which is conducted in the presence of nickel or a nickel alloy.

7. The process of Claim 1 wherein the reaction vessel is packed with silicon carbide or low surface area carbon.

8. The process of Claim 1 wherein the ratio of moles of hydrogen to moles of halocarbon ranges from 0.2 to 5.

9. The process of Claim 2 wherein the halocarbon is $CClF_2CClF_2$, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

10. The process of Claim 2 wherein the halocarbon is CF_3CCl_2F, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

11. The process of Claim 2 wherein the halocarbon is CF_3CHClF, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

12. The process of Claim 2 wherein the halocarbon is CF_3CClF_2, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

13. The process of Claim 2 wherein the halocarbon is CCl_4, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

14. The process of Claim 2 wherein the halocarbon is CF_2Cl_2, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

15. The process of Claim 2 wherein the halocarbon is $CClF_2CHF_2$, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

16. The process of Claim 2 wherein the halocarbon is C_3ClF_7 isomer, the reaction vessel is nickel or a nickel alloy and is either empty or packed with nickel or a nickel alloy, and the reaction time is between 0.2 and 8 minutes.

17. The process of Claim 1 wherein the reaction vessel is either an alloy containing about 76 percent nickel, about 15.5 percent chromium and about 8 percent iron or an alloy containing about 59

percent nickel, about 15.5 percent chromium, about 16 percent molybdenum and about 3.75 percent tungsten; and wherein the reaction vessel either is empty or is packed with an alloy containing about 76 percent nickel, about 15.5 percent chromium and about 8 percent iron, or of an alloy containing about 59 percent nickel, about 15.5 percent chromium, about 16 percent molybdenum and about 3.75 percent tungsten.

18. The process of Claim 1 wherein n is 2 to 10; and wherein the hydrogenolysis is conducted in a reaction vessel of nickel, iron, cobalt, or their alloys which either is empty or is packed with silicon carbide, or low surface area carbon, or with metal pipe, saddles, rings, perforated plates, wire, chips or shot of nickel, iron, cobalt or their alloys, at a temperature within the range of from 350°C to 700°C and for a time sufficient to provide conversion of said halocarbon and to produce as the major product of the conversion, hydrogenolysis product wherein at least one of X of the halocarbon has been replaced by a hydrogen atom.

19. The process of Claim 18 wherein q is 2 to 22, and the major product of the conversion is hydrogenolysis product wherein just one X has been replaced by a hydrogen atom.

20. The process of Claim 1 wherein n is 1, m is 0 to 1, p is 0 to 2, and q is 2 to 4; and wherein the hydrogenolysis is conducted at a temperature within the range of from 350°C to 700°C and for a time sufficient to provide conversion of said halocarbon and to produce as the major product of the conversion, hydrogenolysis product wherein just one X has been replaced by a hydrogen atom.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/05637

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: C 07 C 17/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	C 07 C 17/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	Chemical Abstracts, volume 111, no. 13, (Columbus, Ohio, US), Furutaka Yasuhisa et al.: "Preparation of 1,1,1,2-tetrafluoroethane", & JP, A, 0193549 (DAIKIN INDUSTRIES LTD.) 12 April 1989	1-5,18,20

A	US, A, 2494064 (J.H. SIMONS et al.) 10 January 1950	
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* Special categories of cited documents: [10]
- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
24th January 1991	18 FEB 1991
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	MISS T. TAZELAAR

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

US 9005637
SA 41318

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 11/02/91
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 2494064		None	

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